STRUCTURAL FRONT UNIT GLOBAL APPROACH

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ABSTRACT

The structural design of current vehicle front units has to account for an increasing number of constraints: improvement of real world performance in safety for occupants and others road users, perform in the various ratings and meet future regulations. Therefore the structural car design is the result of a compromise between pedestrian protection, car to car compatibility and self-protection.
In addition to these safety considerations, reparability constraints are becoming more and more demanding and intrusive toward the other safety requirements.
The need to reduce emissions through fuel consumption control requires a reduction of the overall body weight which leads usually to more difficulties to achieve a correct structural behaviour.
Some of these constraints lead to solutions which are in opposition and in general to unsatisfactory compromises. It is suggest to develop a more comprehensive approach in order to better take into account both safety requirements and reparability.
This paper describes the different relevant factors for each safety and reparability requirement, proposes compromise among them in terms of structural aspects. It will also show that it is often difficult to find an answer which satisfies all these aspects.

INTRODUCTION

The previous papers generally covered car-to-car fronto/frontal compatibility. The past few years have shown us that compatibility cannot be treated separately without taking into account the other constraints acting on a front unit. Compatibility cannot be sought at the cost of other road users or to the detriment of the vehicle occupants. Non-aggression towards others (i.e. compatibility of the vehicle with the exterior) extends to the lateral configuration, and to pedestrians impacts. An additional factor to be included concerns the constraints of repair costs due to low speed collisions, and especially to reparability impacts
A final consideration is the requirements of the Euro 2008 standard, that have the direct repercussion of limiting vehicle weight which is not always compatible with passive safety, which generally involves extra weight.
Such constraints taken separately could seriously compromise passive safety for a certain class of configurations and/or road users.
The experience over the past few years of new requirements, associated with a real awareness for safety, is suggesting to approach front-unit design from a global viewpoint. Figure 1 summarises the requirements that a front unit needs to meet. Eventually, to ensure a maximum of passive safety when renewing vehicle populations, front-unit design must as much as possible take into account previous generation vehicles.
Accident research conducted over the last few years clearly show the gains of such improvements could bring. In this paper we will discuss the requirements for each type of modification, the antinomies between them, the approach to a solution, and finally, attempt to define the test configuration which of today is missing to attain this goal.
This paper is based on research studies into passive safety, conducted since 1995.

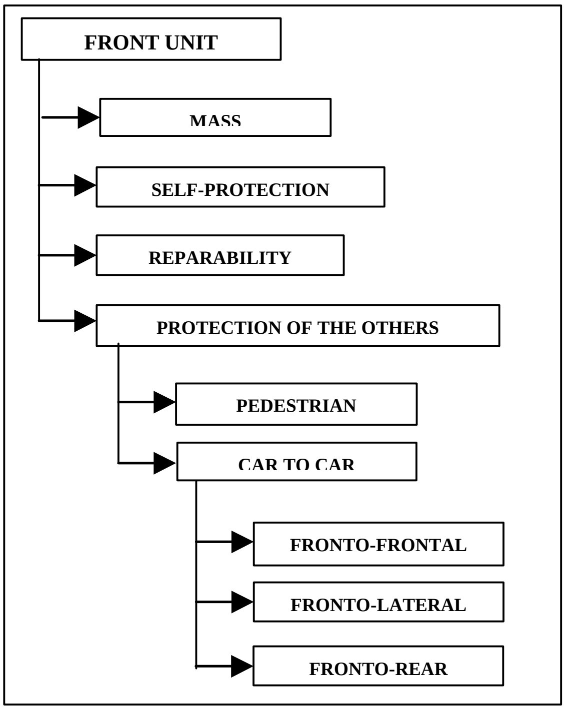


Figure 1: Requirements must be respect by front unit

ACCIDENT RESEARCH

The French vehicle population comprises about 26 million cars, 5 million commercial vehicles and approximately 580,000 buses and trucks. All this in addition to a large number of pedestrians. These very heterogeneous categories naturally use the same network, and it is not surprising that their respective users come into contact with the environment or most frequently, with one another.

The situation on French roads

The following figures came from 1999 survey. Out of the roughtly 8000 persons killed that year, 5200 were in a car. If we remove those fatalities that could have been prevented by the wearing of seatbelts, and considering cases of unclassifiable multiple impacts, the number is reduced to 3200. Therefore accidents with pedestrians and those involving vehicle to vehicle and vehicles against obstacles cost about 3800 lives.
Concerning fatalities in vehicles, two main reasons are attributable. The first is associated with a low level of self-protection. The second results from a high level of aggressiveness. There is here one aspect regarding self-protection (against other cars and fixed obstacles), and another aspect regarding protection of the others.
In most of the cases, occupants suffer serious injuries or death due to passenger-compartment intrusion.

REQUIREMENTS TO APPLY IN VEHICLE DEVELOPMENT

Protection against fixed obstacles

One priority in vehicle design is to protect the vehicle occupants against fixed obstacle collisions. This is today well applied, and indeed has been for many years.

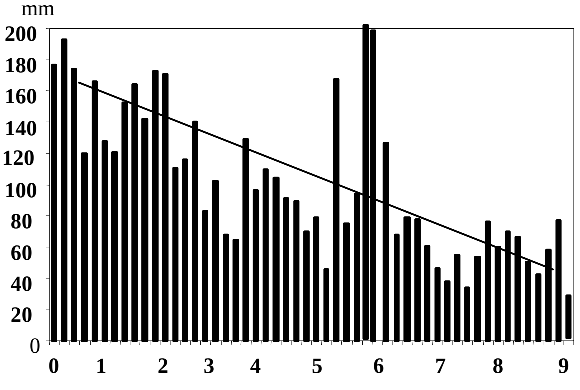


Figure 2 : Compartment intrusion reduction in the last ten years in tests 64 kph offset EEVC barrier

In recent years, all car manufacturers have made significant progresses in structures and restraint systems.

Figure 2 illustrates this progress for a very well known impact configuration - the 64 kph offset EEVC barrier. The degree of intrusion - often around 200 mm at the end of the '80s - becomes down to around zero in the year 2000.
Furthermore, restraint systems, which permitted this reduced intrusion level – have improved just as much, to become “smart”. Such an enormous reduction in the intrusion level could lead to negative consequences. Due to the specific nature of self-protection tests (more stringent for large vehicles), these improvements have driven manufacturers to increase the stiffness not only of their small vehicles, but that of larger ones also. Large vehicles which due to their design are stiffer already ... In effect, the quest for similar intrusion performance, whether for a small or a large vehicle, leads naturally to greater stiffness in the front unit and passenger compartment.
Figures 3 and 4 explain how the increase of deformation loads has allowed the degree of passenger-compartment intrusion to be significantly reduced. Note that large vehicles - even if they are for the most part longer - require higher deformation loads.

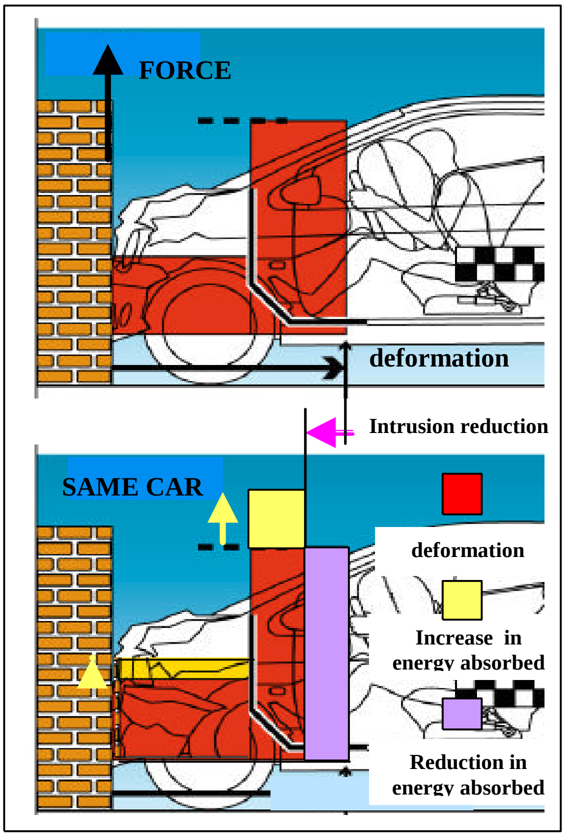


Figure 3 : Increasing stiffness allows to decrease intrusion

These stiffness increase has already proven dangerous for older-generation vehicles, but could also be proved detrimental for car-to-car frontal and lateral compatibility in vehicles of the same generation.
Reducing the intrusion level involves increasing front-end stiffness and also especially the stiffness of the passenger compartment. This increase is likely to be greater for heavy vehicles. The protection involves heavy structural reinforcement, a non-negligible source of weight increase.

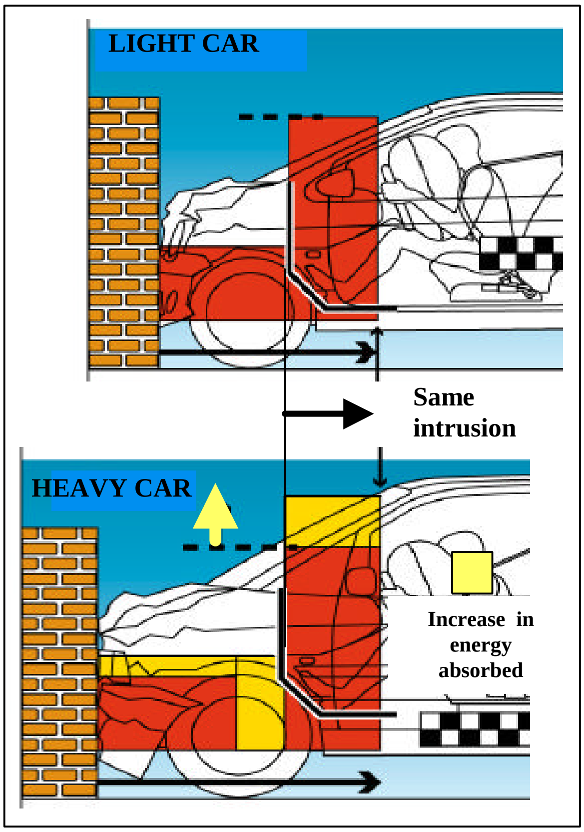


Figure 4 : stiffer heavy car to compensate for the increase in mass

Reducing repair costs

Repairs costs associated with low speed impacts generate heavy expenses for insurance companies. In order to limit these, insurers have over the last few years defined requirements that indirectly determine the design of the front unit. The test configuration is against a rigid wall with 40 % overlap at 15 kph.
One effect is the requirement to reduce the crush distance, and another is to move mechanical components away from the extreme front of the engine compartment, towards the rear (out of the crush zone).
The result for the vehicle design and structure is a large increase in the collapse load of the longitudinals (which represents the only load transfer path in this area), and a reduction in the crushable distance associated with the density of equipment items in the engine compartment.
We will see hereafter that this requirement contradicts the notion of compatibility (high local stiffness) and pedestrian safety (reduction of front padding and under-hood distance due to the equipment density in the engine compartment).
In addition, the increase in stiffness of longitudinal leads to thicker steel sheets and so a non-negligible increase in weight.
Reducing repair costs mainly entails greater stiffness of the forward longitudinal, as well as a high density of mechanical components in the engine compartment, outside of the collapsible section in shown in figure 5.
Addressing the reparability issue also involves employing additional materials - itself leading to increased weight.

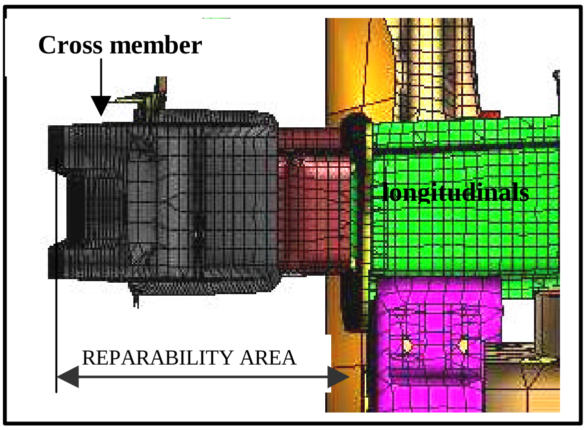


Figure 5: Reparability area of a modern car

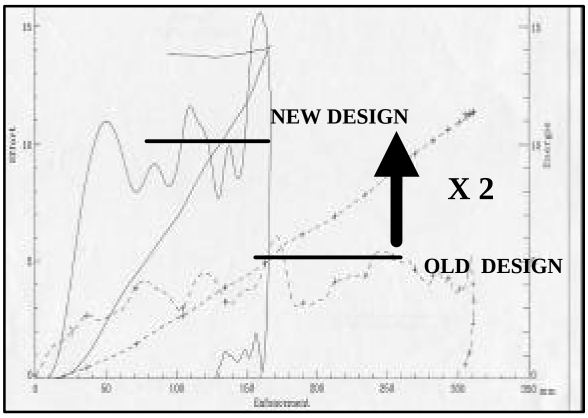


Figure 6: Reparability test impact on longitudinal force evolution

Protection of pedestrians

Despite the decrease of seriously injured pedestrians, accident research still shows need to improve the situation. The present front end shows high stiffness. This is due to stiff structural parts behind the bumper that causes deceleration, displacement and rotation of tibia and lower joint.

Studies show that more than 70 mm of foam between the cross-member and the bumper bar (to decrease the acceleration) as well as a lower contact point (to decrease the rotation) would be necessary to reduce the risk of injuries (Figure 7).

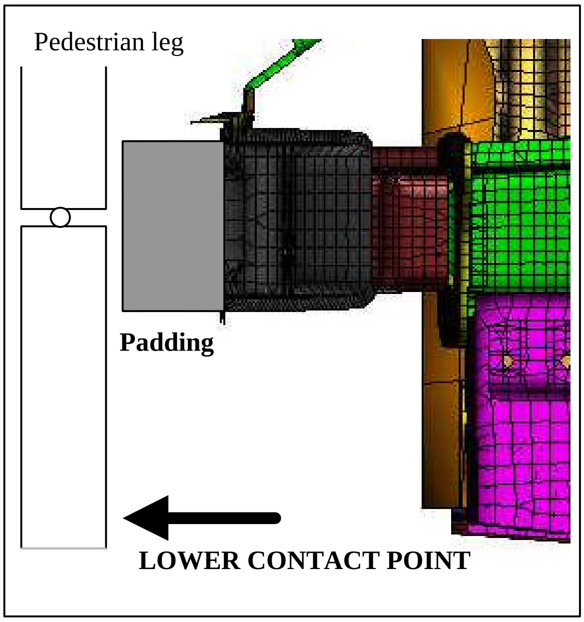


Figure 7 : pedestrian protection requirements, layer and lower load path.

Frontal compatibility

This is one of the most promising ways towards improving road safety. For this reason, efforts in this area were initiated several years ago.
As we have already seen, self-protection without consideration of compatibility may prove aggressive for other vehicles. Additionally, it is relatively easy to define a vehicle concept for impacts against a wall. This is why it is today essential to include the notion of compatibility in modern vehicle development.
Incompatibility in terms of heavy *versus* light is not a fatality; it can be incorporated, as we have already demonstrated between Twingo / Laguna or Clio II / Safrane. Today we should speak rather in terms of "aggressive" and "non-aggressive", because this is where the problem lies. Due to its geometry, layout and stiffness, a front unit can be aggressive for other vehicles.

Background
Compatibility depends on correct distribution of energy between the two vehicles in question. Contrary to certain received ideas, the weight plays no significant role in the energy distribution. Since intrusion is the first cause for mortality (far in front of deceleration), it was seen necessary to decrease this intrusion so that the phenomenon is distributed homogeneously (therefore similar to a test against a fixed obstacle at a speed corresponding to half of the closing speed). The ideal is therefore to achieve a car-to-car situation featuring the same kinetics and performance as it would apply against a wall (Figure 8). Unfortunately two main phenomena associated with the unhomogeneity of front units make it very difficult to reach this objective.

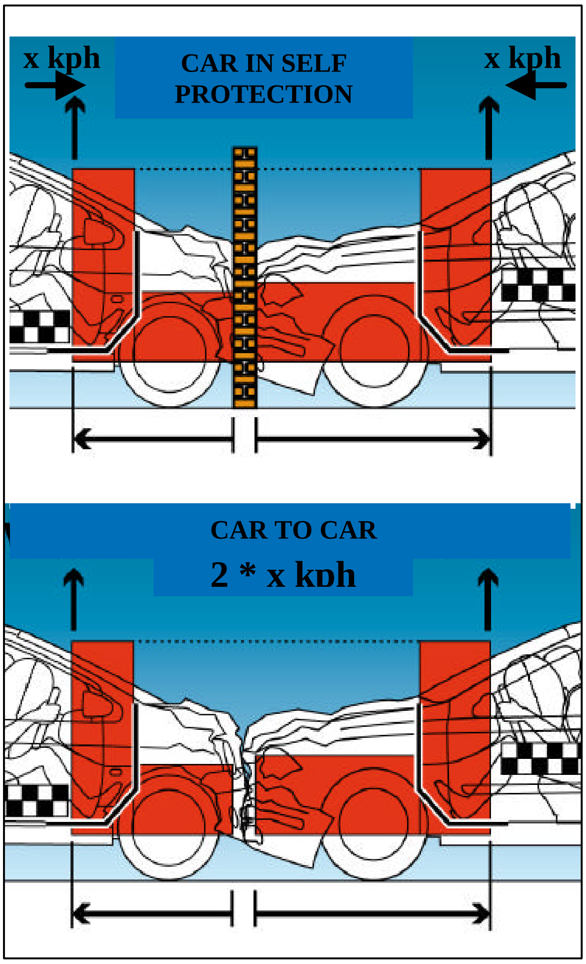


Figure 8: Deformation of two vehicles against a rigid barrier. Theoretical behaviour between two vehicles in head-on impact.

The first is associated with structural overlapping due to lack of a flat interface. This translates into energy loss which can also lead to a more serious phenomenon called over ridding.
The second is associated with the different stiffness between two passenger compartments (self-protection efforts being rarely homogeneous).

The following section briefly summarises these problems, with illustration from accidents.
To ensure a correct compatibility level, the two vehicles should present an homogeneous contact surface (for frontal and lateral impacts), as well as nearly identical passenger-compartment loads before reaching the self-protection load.

Self protection force

As has already been explained, stiffness determines the distribution of energy between the two vehicles. If one of these vehicles stops to be deformed, because it is stiffer, then all the remaining energy is absorbed by the other vehicle. In the following example (Figures 9, 10 et 11) the vehicle 2, by virtue of its greater stiffness, stops to deform, immediately resulting in a larger deformation of vehicle 1.

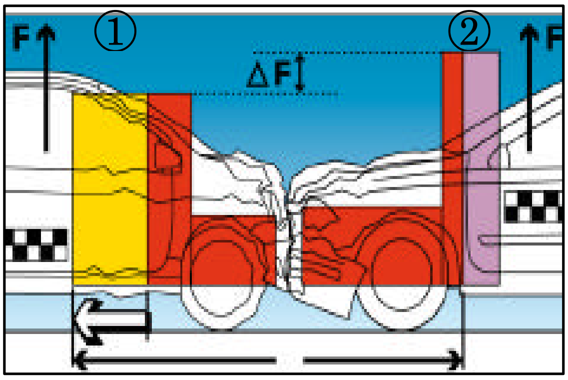
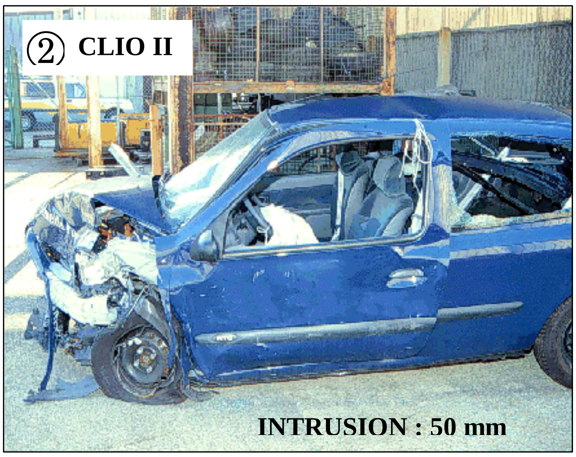


Figure 9: Incompatibility of self protection force between two vehicles

Figures 10 : Real world accident between CLIO I and CLIO II



Energy absorption deficiency

The energy absorption deficiency of the structures results directly from the overlapping of the frontmost elements due to a bad interaction (Figures 11 and 12). The energy absorbed by these elements is therefore less than the one absorbed in a rigid wall impact. This phenomenum increases the fork effect and over riding risk, and consequently the unbalanced energy risk and intrusions.

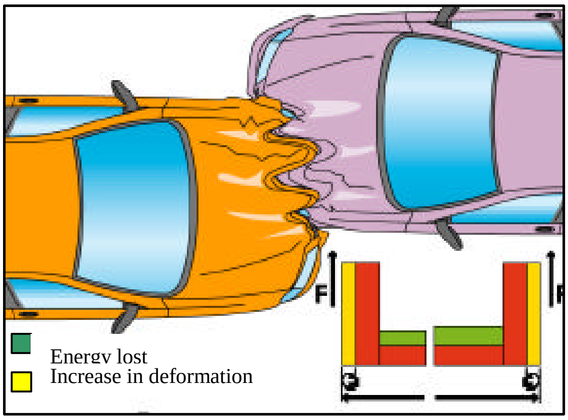


Figure 11 : Energy absorption deficiency in initial car deformation

Figure 12 : Undeformable longitudinal in a real world car to car accident

Over-ridding

Finally, we must note the existence of a phenomenon whose consequences are more serious than those of absorption deficiency: structural over-riding, in other words when one vehicle passes over the other.
The principle behind over-riding is relatively simple: the geometric difference after the initial impact, and the behaviour of the structures during the transition between the beginning and end of the impact event cause one vehicle to rise higher than the other.

The notion of load balancing leads us, before any other task, to define a closing speed up to which we want “to be compatible”.

Lateral compatibility

Efforts undertaken on this theme show the necessity for homogeneous load distribution on the impacted vehicle. Unlike frontal impacts, overlapping of structures may load the occupants directly and reach dramatic proportions.
The requirements are identical to those for frontal impacts, as regard the front ends, with, in addition, very advanced load transfer paths to grab lower structure of the target car. On the other hand, the self-protection forces play no part in this configuration.

Rear compatibility

One of the issue is neck injuries. Even if car manufacturers have made much progress thanks to devices such as head restraints and improvements in seats, it is still necessary to control the deceleration observed in such cases. The reparability requirements demands to limit the front and rear deformation wich is unfortunately in contradiction with the deceleration control necessary to reduce whiplash associated injuries.

CONFLICT BETWEEN REQUIREMENTS

Front-unit stiffness

The need to address protection in fixed obstacles and reparability involves the same requirements: greater stiffness is sought in order to absorb maximum energy for the lowest defomation.
On the other hand, protecting pedestrians requires low stiffness at the very front, then moderate stiffness for frontal compatibility, to avoid overlapping, and for front to rear cars also to avoid high decelerations.
For example, according to the latest studies the pedestrian requires foam thickness of about 70 mm, which runs completely contrary to repair and design criteria.
Additionally, high local stiffness (single load transfer path) associated with reparability countermeasures, is certainly not recommended for frontal compatibility.

Passenger-compartment stiffness

To address protection in fixed obstacles and frontal compatibility demands greater end-of-impact stiffness to limit intrusion. However, in the first case, the deformation forces can only be limited by the restraint system. On the other hand, compatibility involves a notion of "force homogeneity" between the two vehicles. This criterion implies controlling the force down to a certain "violence" level which we will hereafter be refered to as the "compatibility force". This compatibility force can be interpreted as limiting the self-protection load for heavy vehicles, and as increasing it for light vehicles. This "force homogenising" approach allows to be compatible up to the fixed closing speed.

Geometry - architecture

The fixed and rigid obstacle and reparability criteria take no account of geometry or architecture. Considering the rigid nature of the obstacle, front structures will be in all cases still deformed.
Additionally, to decrease repair costs, only one transfer axis exists in the front part of the vehicle, with few or no parts in the collapsible section. These parts take up space elsewhere, which may not only complicate compacting in the engine compartment, but also proves detrimental with respect to the amount of clearance under the hood and the effect for the pedestrian's head.
Frontal and lateral compatibility requires a homogeneous thrust surface. The desired thrust surface tends towards a multiplication of the load transfer paths, with a high degree of interconnectivity. This allows limiting the degree of overlapping in frontal impacts, and loads the lower structures of the impacted vehicle very early on in lateral impacts. These transfer paths may also serve to satisfy pedestrian requirements.

Weight increases

Passive safety and reparability in most cases translate into greater weight. Given increased awareness regarding pollution control and greenhouse effect most car builders are trying to keep the weight of new models as low as possible. This is especially true for cars in compliance with the Euro-2008 standards.
Multiplying the number of load transfer paths could also have the potential to reduce weight.

Observation

As we have seen, it would be rather easy to design a car offering excellent protection against rigid and plane obstacles and reparability because these two requirements are going in the same way. But this could be to the detriment of pedestrians and other vehicles. Real safety in such an approach would have nothing to gain. Reviewing reparability would make the task easier. Unfortunately, the need for reduced repair costs today appears as an essential factor. Therefore the only solution is to identify the best trade-off between repair cost, self-protection, protection of others, and weight-saving.

POSSIBLE IMPROVEMENT

Guidelines for a better front end design

Pedestrians
Multiple and forward load paths, associated with low stiffness, to decrease deceleration and leg rotation.

Reparability
Multiple front end load transfer paths associated with high stiffness, to decrease deformation without increasing the load on the side member.

Self-protection
Multiple load transfer paths associated with greater stiffness in the passenger-compartment, to limit intrusion for both car to car and fixed obstacle collisions.

Front to front collision
Multiple front end load transfer paths, with strong connections and moderate localised forces to limit overlapping and activate the compatibility and self-protection forces. Moderate the force up to the self protection one.

Front to side collision
Multiple and very front end, inter-related load transfer paths, associated with moderate stiffness to limit local intrusions and load the lower transfer paths of the target car.

Front to rear collision
Multiple and front end load transfer paths associated with moderate stiffness, to limit accelerations.

As shown here, the solution that satisfies all the requirements involves a multiple number of strongly inter-related load transfer paths and a progressive increase in stiffness.
The schematic view in Figures 13 and 14 summarises the desirable objective towards which we should be going geometrically. This approach avoids having to increase the longitudinal force, and could decrease the weight significantly.
In terms of energy, compatibility at a given speed (for example 100 kph) requires limiting the deformation load down to an EES of about 50 kph. This load - called the “compatibility load” - should be basically equal for all cars.
After the self-protection load, it would be desirable to be able to maintain a good level of load to avoid total collapse of the passenger compartments due to intrusion effect.

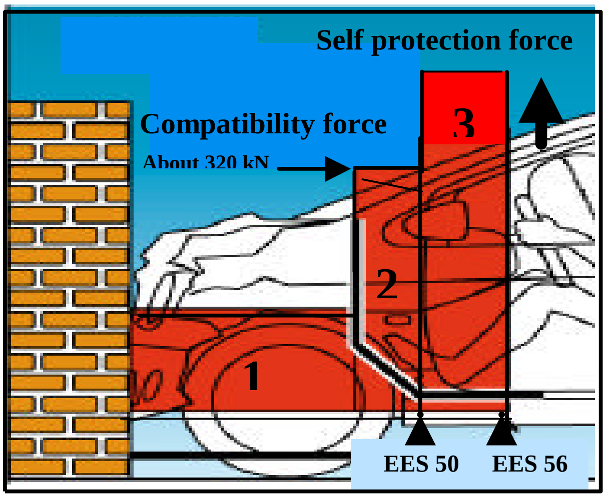


Figure 13 : Force level proposal for 50% overlap

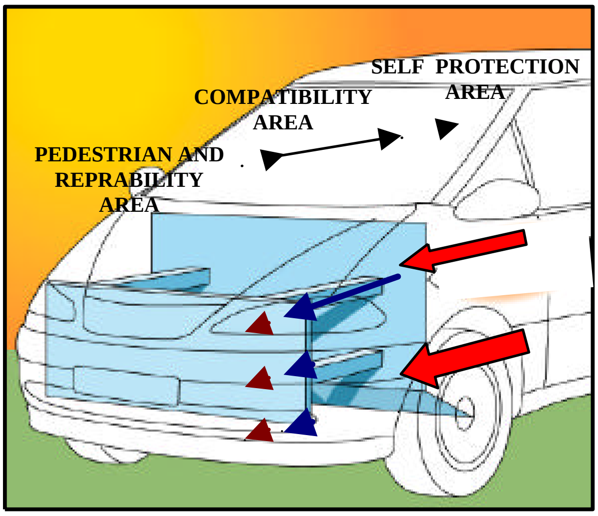


Figure 14: geometrical approach, the front unit must now meet pressure constraints, and not simply force constraints.

TEST CONFIGURATION

While test configurations exist for self-protection, pedestrians and reparability, the same does not apply for compatibility. However, should an improvement be found, it must be applied by all manufacturers if we are to attain our goal. For this reason, Renault proposes filling this gap with an assessment approach, which has already been presented.

The current self-protection test

This test is certainly the best known. Used not so long ago against a rigid barrier, the test today uses an offset deformable barrier in Europe. The configuration allows designing the front unit, as well as a part of the passenger compartment. Due to the presence of a deformable barrier having little rigidity,

all vehicles use the wall behind to collapse front structure, which actually is not so far to testing against a rigid. The energy absorbed by the barrier is practically the same for all vehicles, which makes it more severe for the heaviest (the vehicle EES is increased).
Due to the low stiffness of the barrier and the presence of a wall behind it, this test is not the right one for measuring the level of aggression of the front unit. Only an obstacle looks like a car could answer this question.

Proposals for assessing compatibility

As discussed previously, a minimum of passenger-compartment load is required, associated with sufficient energy absorption in the front unit.

Assessing self-protection

For economic reasons, and in oder to avoid too many test configurations, we may consider that the self-protection impact described earlier could possibly serve as the basis for assessment of passenger compartment load. So, it is sufficient to measure the load behind the barrier in this test.

But if this configuration certainly allows a good assessment of the load onset on the passenger-compartment, it provides no indication about its stability under high intrusion (a mechanism frequently observed in real world accidents).
To answer at this lack, tests at higher violence levels, without dummies, could provide information as to the stability of the passenger compartment (load level, and load resistance).

However, this is necessary but not sufficient A good interaction with the front unit has to be present. This implies no overlapping of the front structures (elimination of fork effect and overlap). Correct functioning in the initial impact phase is quite indispensable. Unfortunately, today, no test configuration proposes verifying the non-aggressiveness of the front unit.

Assessing aggressiveness

The test configuration presented in this paper deals with the non-aggressiveness requirements, and takes into account the introduction of new generations of vehicles. It represents a synthesis of research activities performed during six years and comprising more than 80 tests. The principle is simple, and based on no bottoming-out. It is therefore up to the vehicle to offer a sufficient pushing surface for deformation. This phenomenon corresponds precisely to what is seen in a vehicle / vehicle collisions. The EES sought for the vehicle is about 50 kph (consistent with the 100 kph closing speed).

Proposed barrier

The barrier is derived from ADAC barrier; the main difference is a progressive increase in stiffness in the depth-wise plane, and two height stiffnesses, which contribute to its name: PDB as Progressive Deformable Barrier (Figure 15). The barrier permits problem-free verifying of the thrust surface of the vehicle, and the links between the transfer paths, since its dimensions and stiffness make the bottoming-out phenomenon very unlikely. This barrier, as may be imagined, represent a small car.

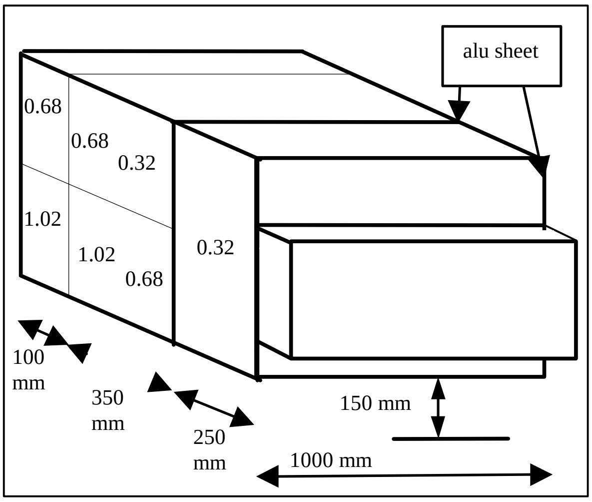


Figure 15 : "PDB" Barrier as Progressive Deformable Barrier derived from ADAC

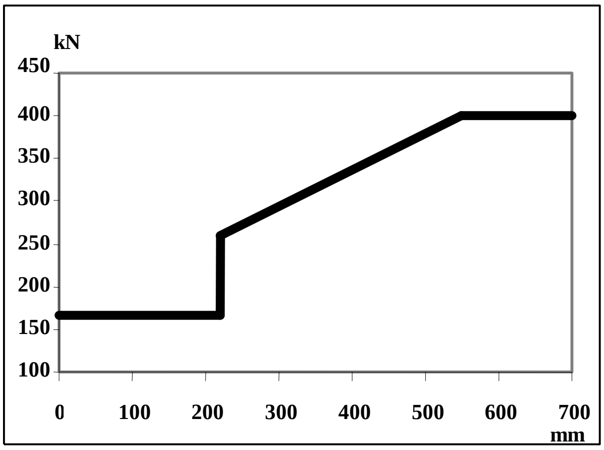
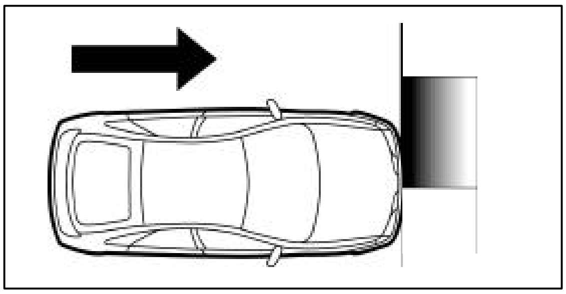


Figure 16 : Barrier force vs deformation corresponding to 750 mm overlap

Method

Test configuration

The objective is the ability to quantify the capacity of the front unit to absorb energy. A speed of 60 kph is sufficient, calculated to take account of the absorption capacities of the barrier as well as the vehicle stiffness.
No test dummies are employed - this is not a restraint-system dimensioning testThe overlap width is 750 mm, meaning that the barrier always generates the same load.



Criteria

Three criteria are proposed but not yet quantified. Proposing quantified criteria would require performing a large number of tests.
The first criteria is the deformation of the barrier. It is clear that a high degree of heavy local force would be marked it. The second is the maximum load measured behind the barrier. The third could be (depending on either the distorted area or the measured load using a multi-cell sensor) the application altitude of the resultant force.
An aggressive vehicle would be identified by large deformation of the barrier and / or substantial local penetration and / or a high overall load and / a centre of forces application that is too high (Figure 17).

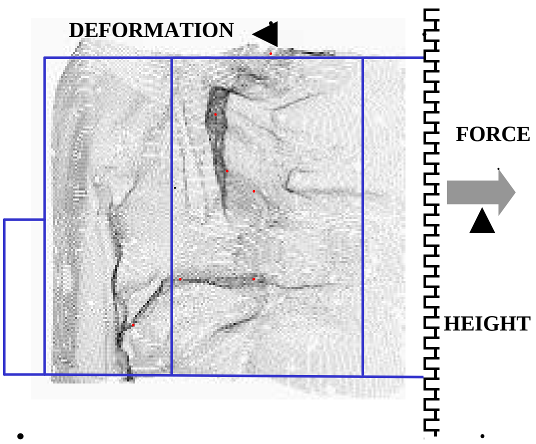


Figure 17: Side view of the barrier, shape, force behind the barrier and resultant force application height

Results

Several tests have already been performed and the first results are very encouraging. Figures 18 and 19 hereafter illustrate two specimen vehicles selected from the existing European models. They were selected for their different front units in terms of design and stiffness. These tests are always accompanied with a car-on-car test in order to validate the judgement of the barrier.

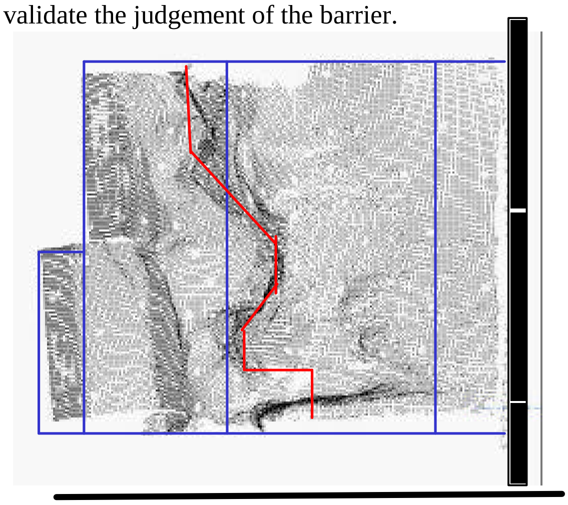


Figure 17: non aggressive car

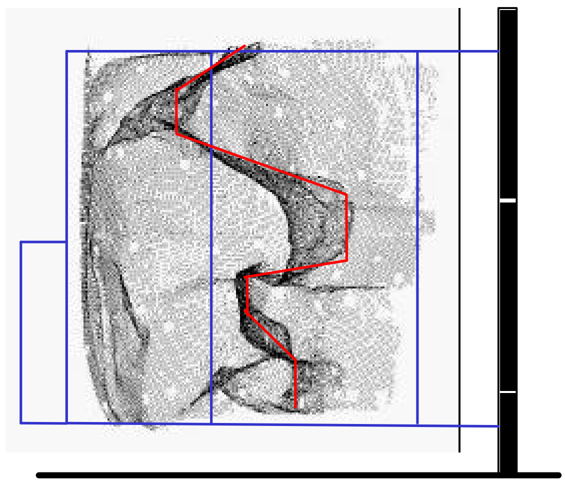


Figure 18: potentially aggressive car

Validation

The survey would not be complete without validating this potential car-to-car aggressiveness. For this reason these vehicles were tested against a target car - a CLIO II known as a small car with acceptable self-protection. The following figures illustrate the damage caused on the CLIO II with an average intrusion level. The previously tested vehicles were also chosen for their similar self-protection forces. The main difference resides, therefore, in the diversity of the respective front units.
The first was judged as non-aggressive by the barrier. The CLIO II, as Figure 19 shows, confirms this

analysis. The second was judged as potentially aggressive. The CLIO II (Figure 20) confirms this analysis also.

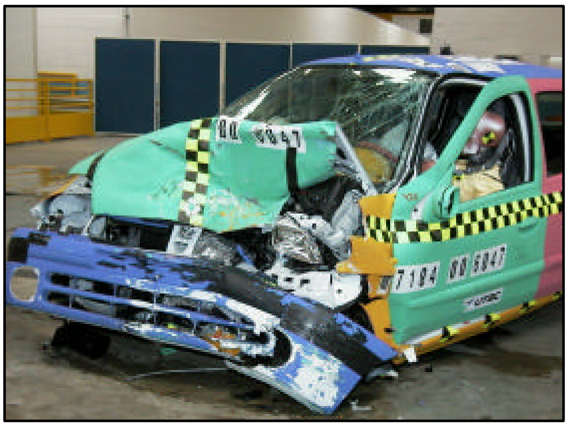


Figure 19: 100 mm intrusion in the Clio II

Figure 20: 260 mm intrusion in the Clio II

CONCLUSION

The aim of this paper was essentially to draw attention to the need for a global approach, since the feasibility of a compromise allows us to cover all of the constraints; there is also the need to control compatibility in all its forms.
Self-protection and reparability driven design could quickly become potentially aggressive for other road users. It is therefore necessary to take into account these users. While regulations and ratings already exist for self-protection, reparability test and soon regulations for pedestrians, there is still nothing as yet regarding compatibility: passenger-compartment stability but also non-aggression. Additionally, considering the renewal period and perpetual changes in the vehicle population, it is also necessary to take into account the previous vehicle generation when developing the new one.
The absence of a compatibility measurement method is today major problem. Yet all agree that compatibility represents a potentially high factor in saving human lives and preventing serious injuries.

A vehicle that meets both self-protection criteria, protection of others, and reparability without nevertheless taking on more weight must take into account the following requirements:

Front unit:
- Must be homogeneous: without local stiffness, and have multiple load transfer paths and rigid links between them;
- Must offer increasing stiffness as penetration increases;
- Must absorb a minimum of energy: load on front unit limited before reaching the self-protection;
- Must meet a maximum load threshold ("compatibility load").

Passenger compartment
- Must meet a minimum "self-protection" load threshold.
- Must be stable: withstand an intrusion load.

The above improvements will only occur through a regulation approach employing two tests, the first to measure the level of self-protection, and the second the level of aggressiveness.
The concept of self-protection against a wall is already very well known. On the other hand, the aspect of aggression is less well-known. The only way of measuring this aggression is by using a test configured against a deformable barrier that excludes any bottoming-out. Only a barrier of this type is capable of optimally represent another vehicle.
The initial results are encouraging and clearly show the high potential of the Progressive Deformable Barrier in identifying vehicle aggressiveness.
Notwithstanding, before setting any for the chosen criteria, further development is needed.

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